NCHRP Project 20-113F

Preparing for Automated Vehicles and Shared Mobility: State-of-the-Research Topical Paper #2

SAFETY SCENARIOS AND ENGAGEMENT DURING TRANSITION TO HIGHLY AUTOMATED VEHICLES

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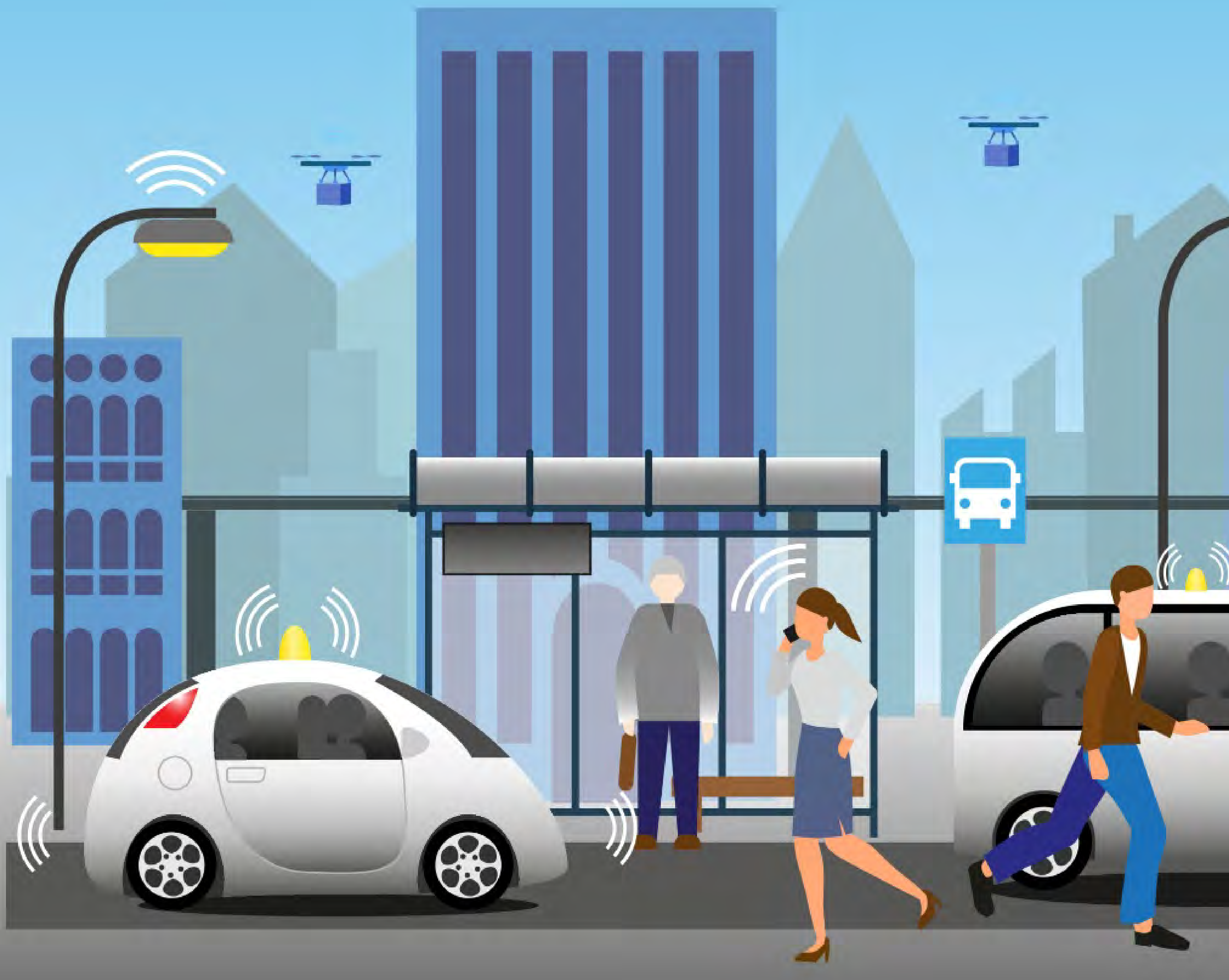
TRB AV/SM FORUM
AUTOMATED VEHICLES + SHARED MOBILITY

1 Introduction

1.1. Background

In coordination with the National Cooperative Highway Research Program (NCHRP), the TRB Forum on Preparing for Automated Vehicles and Shared Mobility (Forum) has developed nine (9) Topical Papers to support the work of the Forum (Project).

The mission of the Forum is to bring together public, private, and research organizations to share perspectives on critical issues for deploying AVs and shared mobility. This includes discussing, identifying, and facilitating fact-based research needed to deploy these mobility focused innovations and inform policy to meet long-term goals, including increasing safety, reducing congestion, enhancing accessibility, increasing environmental and energy sustainability, and supporting economic development and equity.



The Topical Areas covered as part of the Project include the following:

- Models for Data Sharing and Governance
- Safety Scenarios and Engagement during Transition to HAVs
- Infrastructure Enablers for Automated Vehicles and Shared Mobility
- Maximizing Positive Social Impacts of Automated Vehicle Deployment and Shared Mobility
- Prioritizing Equity, Accessibility and Inclusion Around the Deployment of Automated Vehicles
- Potential Impacts of HAVs and Shared Mobility on the Movement of Goods and People
- Impacts of Automated Vehicles and Shared Mobility on Transit and Partnership Opportunities
- Implications for Transportation Planning and Modeling
- Impacts and Opportunities Around Land Use and Automated Vehicles and Shared Mobility

For this Project, the important goals of the papers are to provide a snapshot of all research completed to date for a Topical Area and within the proposed focus areas identified below. The papers are intended to provide a high-level overview of the existing research and to make recommendations for further research within a Topical Area. The Project establishes a foundation to guide the use of resources for further development and support of more comprehensive research that tracks the identified research gaps noted in each Topical Paper and to support the Forum.

The research reviewed varies by paper, but generally, only published research was included as part of the Project. For clarity, the scope of the project is to report on research that has been done without judging or peer reviewing the research conducted to date and referenced herein. While considered for background purposes, articles, blog posts, or press releases were not a focus for the work cited in the Topical Papers. Also, in consideration of the focus of the Forum and the parameters of the Project, the research was narrowed to publications focused on the intersection between automated vehicles and shared mobility. Materials reviewed and cited also include federal policy guidance and applicable statutes and regulations.

Each of the papers are written to stand on its own while recognizing there are cross over issues between the Topical Areas. If desired, readers are encouraged to review all 9 Topical Papers for a more comprehensive view of the Project and the points where topics merge.

The goals of the Topical Papers are the following:

Snapshot of research completed under a particular topic area

Summary of research completed to date

Identification of gaps in research

Recommendations for additional research

1.2. Approach to Topical Paper Development

The approach to development of the Topical Papers and their focus included the following:

- Meetings with the Chairs of the Forum
- Engagement with the Members of the Forum, including during the Forum meetings in February and August of 2020
- Feedback from Chairs and Forum Members during the development of focus areas for the Topical Papers and receiving comments to the draft versions of the papers

During the meetings with the Forum in February 2020, the research team discussed the Project with the Forum over two days in two separate sessions. On Day 1, the research team presented the proposed scope for each Topical Paper and broke out into break-out groups to further refine the focus of each paper to match the interest and goals of the Forum and its Members. During Day 1, the Forum also heard from different organizations highlighting previous and ongoing research. These organizations[1] included the following:

- Brookings Institution
- The Eno Center for Transportation
- National Governors Association
- Future of Privacy Forum
- AARP
- American Public Transportation Association

On Day 2, the research team reconvened with the Forum to summarize the break-out discussions on Day 1 and to receive final comments on the focus for each Topical Paper.

In August 2020, the draft papers were presented to the Forum for review and feedback. Comments were received in writing and verbally during a virtual Forum meeting. The final papers incorporate the comments and feedback received as part of the review process. This paper identifies a large body of research regarding this topic area associated with shared and automated vehicles. As reviewer comments pointed out, there remains considerable uncertainty regarding if and when highly automated vehicles will be deployed on a large scale. This is reflected in much of the research that has been completed to date. Consequently, this paper summarizes common themes from the research available to date as much as possible, while acknowledging that various scenarios may impact the issues, recommendations, and areas for future research. Many of the issues addressed in this research are forward-looking and anticipate an environment where fully automated vehicles (SAE Level 5) are a ubiquitous part of the transportation system.

[1] The research team and the Forum thank these organizations for their time in sharing their work and insights in support of the development of the Topical Papers.

2 Paper Areas of Focus

This Topical Paper reviews research conducted and published as of July 10, 2020, unless specific papers were identified as part of the final review and comments process. In approaching this topic, the paper focuses on the following issue areas:

1. Assess new approaches to safety needed to support the ongoing deployment of automated and connected vehicles in expected use cases
   a. Consider time horizons with research on transition period, including short, medium, and long-term
2. Address definition of “safety scenarios” and consideration of safety assurance from a practical/operations perspective
3. Evaluate roles and responsibilities for safety and identify issues for development of safety metrics
4. Rethink driver education and mobility engagement, including on AVs, micromobility, and identify models to ensure user understanding of capabilities of technology
5. Consider coordination with traffic and law enforcement, including consideration of existing powers of states and local governments, particularly over vehicle registration and licensing, right-of-way management, and how these impacts potential regulation of AVs, especially with regard to curb management
6. Address new potential concerns related to public health, including impacts from COVID-19

3 Summary of Findings

While HAVs are considered by many to offer safety benefits, the public remains skeptical of their safety. Many safety concepts currently in practice for traditional vehicles are applicable but the testing and creating of regulatory standards for AVs in the traditional manner will take decades to complete. Appreciating this, government, the research community, and the private sector wish to understand how to best ensure safe operation of AVs, to test AVs effectively and efficiently, and determine what kinds of standards should be established.

Original equipment manufacturers (OEMs) and start-ups have researched and implemented testing protocols at a range of testing facilities that are operated both privately and under the auspices of nonprofits and universities. Most of that research is proprietary and is not available for outside review or public scrutiny.

Reviewing the body of literature on safety scenarios, testing, and safety framework considerations brings to light several key themes:

- **Safety Scenarios are a core building block in most alternative approaches to assure the safety of HAVs.** The safety scenarios or test cases represent relevant safety situations that a vehicle may encounter. Whether developing a safety case or a safety assurance framework, safety scenarios are at the center of most approaches to demonstrating the safety of AVs. In the U.S. much of this work is proprietary, although several developers have released thousands of safety scenarios. Projects in Germany and Japan have also generated safety scenarios and placed these within a framework of safety cases or safety management systems. A notable exception is the nascent efforts of the City of Sacramento to create safety scenarios for the urban environment.
- **While there appears to be some movement in releasing incident information and even sharing safety scenarios developed by OEMs and start-ups, most research on testing remains proprietary.**
- **The roles and responsibilities in creating, adopting, and enforcing regulatory safety standards follow traditional federal, state, and local allocation of responsibility.** While there has been significant debate about whether to shift responsibilities to the federal government, most of the research indicates that consistency goals can be achieved through other means.
- **Exclusive reliance on test track and road testing is likely to take too long to complete.** Alternatively, simulation coupled with test safety scenarios may prove much more efficient in establishing safety cases and safety assurance frameworks.
- **Approaches such as third-party validation or performance-based standards are new safety methods under development.** However, little research to date has focused on developing or assessing either approach. The traditional concepts and approaches to setting standards embodied in the Federal Motor Vehicle Safety Standards framework are slow and do not account for either ODDs or the artificial intelligence involved in HAVs. Performance based standards undergirded by safety scenarios offer an alternative to using standards developed for vehicles without ADS. Third party validation or certification similar to that in the aviation arena have been suggested, but little work has been done to establish how these would apply in the area of HAVs.

- **Demonstration programs can provide meaningful lessons and the opportunity to evaluate safety assurance programs in a constrained environment with a single modal vehicle type.** However, these controlled demonstration projects do not address managing safety in an operational environment that includes different levels of automation and different vehicle types.

4 Summary of Research Reviewed

The research reviewed included papers from academic journals, federal entities, and special interest groups. This points to a cross-sector interest in prioritizing safety in the transition to highly AVs. Organizations that raised concerns around AVs and safety included the Rand Corporation and NHTSA. The following is a summary of the research reviewed.

4.1. Assess new approaches to safety needed to support the ongoing deployment of automated and connected vehicles in expected use cases. Consider time horizons with research on transition period, including short, medium, and long-term.

A large body of research on safety and AVs is centered around the new approaches to safety needed to support the deployment of AVs. The federal government, automakers, and third-party research facilities have engaged in research activity around safety testing protocols and development of decision support tools around assessing whether AVs can operate in compliance with the rules of the road in a given operating environment. This research is critical as OEMs, researchers, and stakeholders work through which regulations meet public interest in improving road safety and ensuring safe operation of specific vehicles. The development of the regime may occur through rulemaking or consensus standards, federal inspection and enforcement or third-party consensus standards coupled with a transparent validation of compliance. In the meantime, AVs across modes are being tested in constrained environments and on limited access highways in many parts of the U.S. and globally. Expected use cases in the short-term include low-speed AVs, transit vehicles, and SAE Level 3 and Level 4 applications in highway driving. For heavy-duty vehicles near-term examples include SAE Level 1 and Level 2 platooning and SAE Level 3 trucks in ports or other constrained off-road environments. Expected use cases in the medium term include AV taxis. Expected use cases in the long-term are light-duty vehicles. Most of the work on AV safety relates to how vehicles should be tested to develop a safety case combined with other tools such as simulations and process audits.

4.1.1 New Approaches to Testing, Standards, Ensuring Safety

One set of approaches for testing includes test tracks, simulation testing, and on-road driving. Kalra and Paddock (2016) observe that sufficient testing cannot occur through driving as that would require documentation of millions and potentially billions of miles to demonstrate their reliability in terms of fatalities and injuries.[2] To log that level of mileage, even under aggressive testing, would take hundreds of years to accomplish. Thus, they have suggested another metric as discussed further in Section 4.3.2.[3]

The National Transportation Safety Board (NTSB) found that there is a need for safety risk management requirements for testing AVs on public roads.[4] As a result, the NTSB recommended requiring OEMs who are or will test a developmental ADS on public roads to submit a safety self-assessment report to NHTSA. They also recommended that NHTSA establish a process for the ongoing evaluation of the safety self-assessment reports and determine whether the plans include appropriate safeguards for testing a developmental ADS on public roads (as further discussed below).[5] NHTSA has requested voluntary safety assessments by vehicle developers as another approach to demonstrating safe practices in testing and operations.[6]

Given the challenges of implementing a governmental regulatory and enforcement regime, some, including former NTSB Chair Chris Hart, have suggested third-party validation. The idea of third-party testing and validation would introduce transparency into safety practice without compromising competitive information and would raise the public's confidence in the safety of these vehicles.

The European Union's Pegasus Project based in Germany and the Sakura Project in Japan have each worked to coordinate standard setting activities focused primarily on safety scenarios. The Pegasus Project is developing a generally accepted and standardized procedure for testing and approval of automated driving.[7] The Sakura Project's focus is to harmonize data acquisition, develop research methodologies, and coordinate standards activities.[8] The Sakura Project has released research on creating and using testing scenarios.[9]

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[2] Nidhi Kalra and Susan M. Paddock, "Driving to Safety: How Many Miles of Driving Would It Take to Demonstrate Autonomous Vehicle Reliability?," *Transportation Research Part A: Policy and Practice* 94 (2016): 182–93, https://doi.org/10.1016/j.tra.2016.09.010.
[3] Kalra and Paddock.
[4] National Transportation Safety Board, "Collision between Vehicle Controlled by Developmental Automated Driving System and Pedestrian, HWY18MH010, Tempe, Arizona," 2019, 1–78, https://www.ntsb.gov/investigations/AccidentReports/Reports/HAR1903.pdf.
[5] National Transportation Safety Board.
[6] Araz Taeihagh and Hazel Si Min Lim, "Governing Autonomous Vehicles: Emerging Responses for Safety, Liability, Privacy, Cybersecurity, and Industry Risks," *Transport Reviews* 39, no. 1 (2019): 103–28, https://doi.org/10.1080/01441647.2018.1494640.
[7] Pegasus, "Pegasus Research Project," https://www.pegasusprojekt.de/en/about-PEGASUS (Accessed September 2 2020)
[8] Satoshi Taniguchi, "Automated Driving Safety Assurance in Japan," 2020.
[9] Taniguchi.

4.1.2 Safety Culture

In the aftermath of an Uber AV crash in Tempe, AZ, NTSB's report on the crash found that Uber's Advanced Technology Group had an inadequate safety culture.[10] This finding builds on a significant level of research including both crash investigations in transportation as well as occupational health and safety files. An outside firm retained by Uber to review the company's safety culture also found that Uber needed to improve its safety management system and the overall safety culture, as well as implement training, safety policies, and procedures.[11] On a similar note, Underwriter Laboratories' UL4600 includes a section on developing a safety culture; focusing on the role of safety culture of the developer and supply chain in risk identification and mitigation.[12]

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[10] National Transportation Safety Board, "Collision between Vehicle Controlled by Developmental Automated Driving System and Pedestrian, HWY18MH010, Tempe, Arizona."
[11] Mark A. Dombroff, David K. Tochen, and Christopher A. Hart, "Independent Review of the Safety Culture of Uber Technologies, Inc.'s Advanced Technologies Group Final Report," 2018.
[12] Underwriter Laboratories, "UL 4600 Standard: Standard for Evaluation of Autonomous Products," 2020.

4.1.3 Cybersecurity

A key theme in the research on cyber security was the potential seriousness of consequences of cybersecurity threats. The research focused on safety attacks rather than efficiency attacks. Safety attacks are those on the vehicle designed to "weaponize" the vehicle, turning it into a safety hazard. Efficiency or enterprise attacks target the logistics system of AVs and affect their operations.

The U.S. Department of Homeland Security (2017) found that AVs will have many positive benefits for society, but they also introduce new cybersecurity risks.[13] This derives from the fact that as components become increasingly integrated and extend into external networks, they become more vulnerable to hackers. Risks include potential attacks against multiple vehicles at once and increased opportunity for attacks as more vehicle components join the "Internet of Things."[14]

Garcia et al. (2015) identify two types of vehicle security: in-vehicle security and cybersecurity.[15] In-vehicle security exists to guard against tampering with electronic and computerized systems, either from within or from an external source communicating with a vehicle. As automobile manufacturers develop more options for connectivity the opportunities for breaching in-vehicle security increase.

Cybersecurity refers to the protections for the vehicle sensors and systems in the vehicle that actively communicate with other systems or other vehicles. Much of the work done to date on developing security systems for future AVs and connected vehicle systems has been sponsored by the USDOT and is intended to explore how to design systems that address several national priorities for security and privacy.[16]

Another primary area in research around cyber-related issues is the risk of lax security and unprotected vehicles. Yeh et al. (2018) describe the technology and common cybersecurity attacks a vehicle could face.[17] They detail three principle potential attacks on the automotive radar: jamming, spoofing, and interference. First, jamming is the transmission of radio frequency signals to interfere with a radar by saturating its receiver with noise. Second, spoofing is the replication and retransmission of radar transmit signals designed to provide false information to a radar to corrupt received data. Third, interference is the intentional or unintentional modification or disruption of a radar signal due to unwanted signals, such as signals from different automotive radars. In general, dedicated short-range communications (DSRC), wireless technologies, and Wi-Fi are susceptible to similar types of attacks.[18] Hardening DSRC technologies includes protecting against assaults on user confidentiality. DSRC devices need to

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[13] Office of Cyber Analysis Insfrastructure, "FUTURE ENVIRONMENT NET ASSESSMENT: Autonomous Vehicles," no. June (2017).

[14] Office of Cyber Analysis Insfrastructure.

[15] Dominie Garcia et al., "Revolutionizing Our Roadways: Cybersecurity Considerations for Connected and Automated Vehicle Policy," 2015, 22p, http://tti.tamu.edu/documents/TTI-2015-2.pdf%0Ahttps://trid.trb.org/view/1353736.

[16] Garcia et al.

[17] Enoch R. Yeh et al., "Cybersecurity Challenges and Pathways in the Context of Connected Vehicle Systems (134)," no. February (2018), http://www.ntis.gov.

[18] Yeh et al.

maintain information privacy and to ensure that unwanted third parties cannot covertly track the location of the device over an extended period.[19]

Key research on cybersecurity and AVs focuses on privacy protections; in this area the federal role is limited in scope and reach. A specific topic is trip trackability. In this area, Garcia et al. state that automobile manufacturers are conducting research on protecting any potentially identifiable information from the vehicle. They have additional research efforts into how to integrate DSRC-based devices without requiring vehicle information such as the vehicle identification number.[20] Zenzic (2020) argues that states will be responsible for many privacy protections and therefore must understand vehicle-to-vehicle safety security system design to determine if additional privacy protection measures should be developed.[21] It is expected that the more stringent privacy measures will first be set in the policy and institutional areas and then implemented in the technical realm.[22]

4.1.4 Active Research Efforts and Projects

Several active projects and efforts cover new approaches to safety. One is the AV Transparency and Engagement for Safe Testing Initiative from NHTSA. Groups testing AVs can now submit testing information to NHTSA to inform the public. The largest group of projects is the USDOT ADS Demonstration Grant awardees. Many of these projects focus on safety and the transition to AVs across various use cases. For example, Texas A&M University's project "Engineering Experiment Station" focuses on the safe integration of AVs on suburban and rural roads, with a database for safety analysis. Virginia Tech Transportation Institute's project "Safety Operating ADS in Challenging Dynamic Scenarios: An Optimized Automated Driving Corridor Demonstration" focuses on the safe operation of an ADS in highly dynamic scenarios on an automated corridor.

4.2 Address definition of "safety scenarios" and consideration of safety assurance from a practical/operations perspective

Safety scenarios, both public and proprietary from within the industry, are a heavy area of research concentration with trends towards consideration of safety cases.

4.2.1 Safety Scenarios

Safety scenarios are specific, quantitative descriptions of a time interval detailing, through a defined set of state variables or parameters, events and activities performed by a relevant set of dynamic agents in an ODD.

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[19] Yeh et al.
[20] Garcia et al., "Revolutionizing Our Roadways: Cybersecurity Considerations for Connected and Automated Vehicle Policy."
[21] Zenzic, "Cyber Resilience in Connected and Automated Mobility (CAM) Cyber Feasibility Report," no. May (2020): 1–26.
[22] Yeh et al., "Cybersecurity Challenges and Pathways in the Context of Connected Vehicle Systems (134)."

Some of the most significant work on safety scenarios comes from the Pegasus Project in Germany and the Sakura project in Japan. The Pegasus Project attempts to answer "how safe is safe enough" by creating a scenario-based method to assess automated driving.[23] The scenarios depict traffic events and can be tailored to test specific pieces of a function. The Sakura project is working to create a scenario-based methodology for safety assurance and a scenario database.[24] The scenarios include traffic disturbance scenarios for vehicle judgement, vehicle stability scenarios to see vehicle control, and perception disturbance scenarios for perception.[25]

Several key pieces of work center around how to effectively create robust safety scenarios. More recent work has focused on safety standards and a safety case. Koopman and Fratrik (2019) identify factors that are relevant for validation of the system, including ODD, OEDR, vehicle maneuvers, and fault management.[26]

SAE's Automated Vehicle Safety Consortium (2020) describes ODDs for safety scenarios. This document provides a conceptual framework and the associated parameters of interest, along with operational definitions, that manufacturers and developers can use to describe an ADS ODD. The document seeks to establish commonly defined terms and a framework in which to apply them.[27]

A viable approach requires feedback paths to ensure that both the safety case and the standard itself evolve with the technology and accumulated experience

Koopman et al. (2019) introduce the idea of a safety case in developing safety standards. A safety case is a document produced by the operator of a facility that identifies the hazards and risks, describes how the risks are controlled, and describes the safety management system in place to ensure the controls are effectively and consistently applied. They propose a safety scenario approach based on setting scope requirements for an overarching safety case. They indicate that a viable approach requires feedback paths to ensure that both the safety case and the standard itself evolve with the technology and accumulated experience.[28] These four authors are also the subject matter experts for the UL 4600, published in April 2020, which is developed around a safety case.[29] A variety of similar literature was also reviewed.[30]

Several research efforts are ongoing around safety scenarios. MCity at the University of Michigan has created the MCity ABC test, which is intended to verify that an AV can handle a

23 Lutz Eckstein, "The PEGASUS Project – Results and Future Prospects," 2019.
24 Taniguchi, "Automated Driving Safety Assurance in Japan."
25 Satoshi Taniguchi, "Automated Driving Safety Assurance in Japan," 2020.
26 Philip Koopman and Frank Fratrik, "How Many Operational Design Domains, Objects, and Events?," *CEUR Workshop Proceedings* 2301 (2019): 1–4.
27 SAE ITC Automated Vehicle Safety Consortium, "Automated Vehicle Safety Consortium Best Practice for Describing an Operational Design Domain: Conceptual Framework and Lexicon," 2020.
28 Philip Koopman et al., "A Safety Standard Approach for Fully Autonomous Vehicles," *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)* 11699 LNCS, no. 19 (2019): 326–32, https://doi.org/10.1007/978-3-030-26250-1_26.
29 Underwriter Laboratories, "UL 4600 Standard: Standard for Evaluation of Autonomous Products."
30 Similar literature includes a report from Transport Systems Catapult, "Regulating and Accelerating Development of Highly Automated and Autonomous Vehicles Through Simulation and Modeling" and the Rand Corporation's "Driving to Safety: How Many Miles of Driving Would It Take to Demonstrated Autonomous Vehicle Reliability?"

variety of different safety scenarios.[31] The Pegasus Joint Project is a German effort to develop a generally accepted and standardized procedure for the testing and approval of automated driving functions to facilitate the rapid implementation of automated driving into practice.[32]

4.2.1.1 Safety Frameworks

One key piece of work on safety scenarios comes from the Rand Corporation; Fraade-Blaner et al. aid in crafting a framework for measuring AV safety to contribute to the public discussion around that topic.[33] The authors present a framework for safety scenarios across settings, stages of deployment, and measurements. Settings refer to the situational context in which AVs operate and include simulations, closed courses, and public roads both with and without a safety driver. Stages of deployment include development, demonstration, and deployment. Fraade-Blanar et al.'s view is that the transition to deployment indicates that a threshold level of safety has a been reached for the general public (although this is not based on specific laws or regulations). Fraade-Blanar et al. also include recommendations related to standards, processes procedures and design, leading measures, and lagging measures in measures.

Thorn, Kimmel, and Chaka (2018) develop a test scenario framework that incorporates elements of ADS features, ODD, OEDR, fail-operational (when the ADS can continue to operate) and fail-safe (when the ADS cannot continue to operate) strategies.[34] The suggested framework uses a checklist-type approach to identify high-level scenario tests by specifying relevant tactical maneuvers, ODD, OEDR, and potential failures. Each of these components are then further specified to develop a comprehensive set of procedures for a given scenario test.[35] Similar literature is included in footnote 36.[36]

4.2.2 Safety Assurance

Literature on safety assurance is focused on the industry. Industry groups and OEMs have had the primary job of safety assurance and they are expected to continue in that role. Crist and Voege (2018) state that OEMs have had and will continue to have the primary responsibility for safety testing of their AVs and these organizations must be able to provide safety assurance through independent validation or certification of their security processes and products.[37] Shalev-Shwartz, Shammah, and Shashua (2017) presented the idea of safety assurance through a mathematical model. The Responsibility-Sensitive Safety formalizes an interpretation

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[31] Heui Peng, "Conducting the Mcity ABC Test : A Testing Method for Highly Automated Vehicles," no. April (2020): 1–14.
[32] Karsten Lemmer, "PEGASUS Effectively Ensuring Automated Driving," 2017.
[33] Laura Fraade-Blanar et al., *Measuring Automated Vehicle Safety: Forging a Framework*, *Measuring Automated Vehicle Safety: Forging a Framework*, 2018, https://doi.org/10.7249/rr2662.
[34] Eric Thorn, Shawn Kimmel, and Michelle Chaka, "A Framework for Automated Driving System Testable Cases and Scenarios," *Dot Hs 812 623*, no. September (2018): 180, https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13882-automateddrivingsystems_092618_v1a_tag.pdf.
[35] Thorn, Kimmel, and Chaka.
[36] Similar literature includes Every et al.'s "A Novel Method to Evaluate the Safety of Highly Automated Vehicles," NIST's "Workshop Report: Consensus Safety Measurement Methodologies for Automated Driving System-Equipped Vehicles," and the U.S. DOT and NHTSA's "Automated Driving Systems (ADS) – A Vision for Safety 2.0"
[37] Philippe Crist and Tom Voege, "Safer Roads with Automated Vehicles?," 2018, 1–46, https://www.itf-oecd.org/sites/default/files/docs/safer-roads-automated-vehicles.pdf.

of "Duty of Care" from tort law stating that an individual should exercise "reasonable care" while performing acts that could harm others.[38]

4.3 Evaluate roles and responsibilities for safety and identify issues for development of safety metrics

Roles and responsibilities for safety have been an important area of study over the past several years, along with the development of safety metrics. There is more consensus on the former than the latter. Much of the work on safety roles and responsibilities comes from the federal and state governments. As more AVs are adopted, more research is expected around the role of states as they adapt. Much of this work on the development of safety metrics builds on the responsibilities for safety of regular automobiles. Various metrics have been considered at the federal level, without consensus on one standard. The metric often used by the industry is disengagements as this is required in locations such as California. However, it has limited usefulness without consistent and clear reporting.

4.3.1 Roles and Responsibilities for Safety

NHTSA documents the roles and responsibilities for safety testing standards, and enforcement as between states and the federal government.[39] In brief, the roles are as follows:

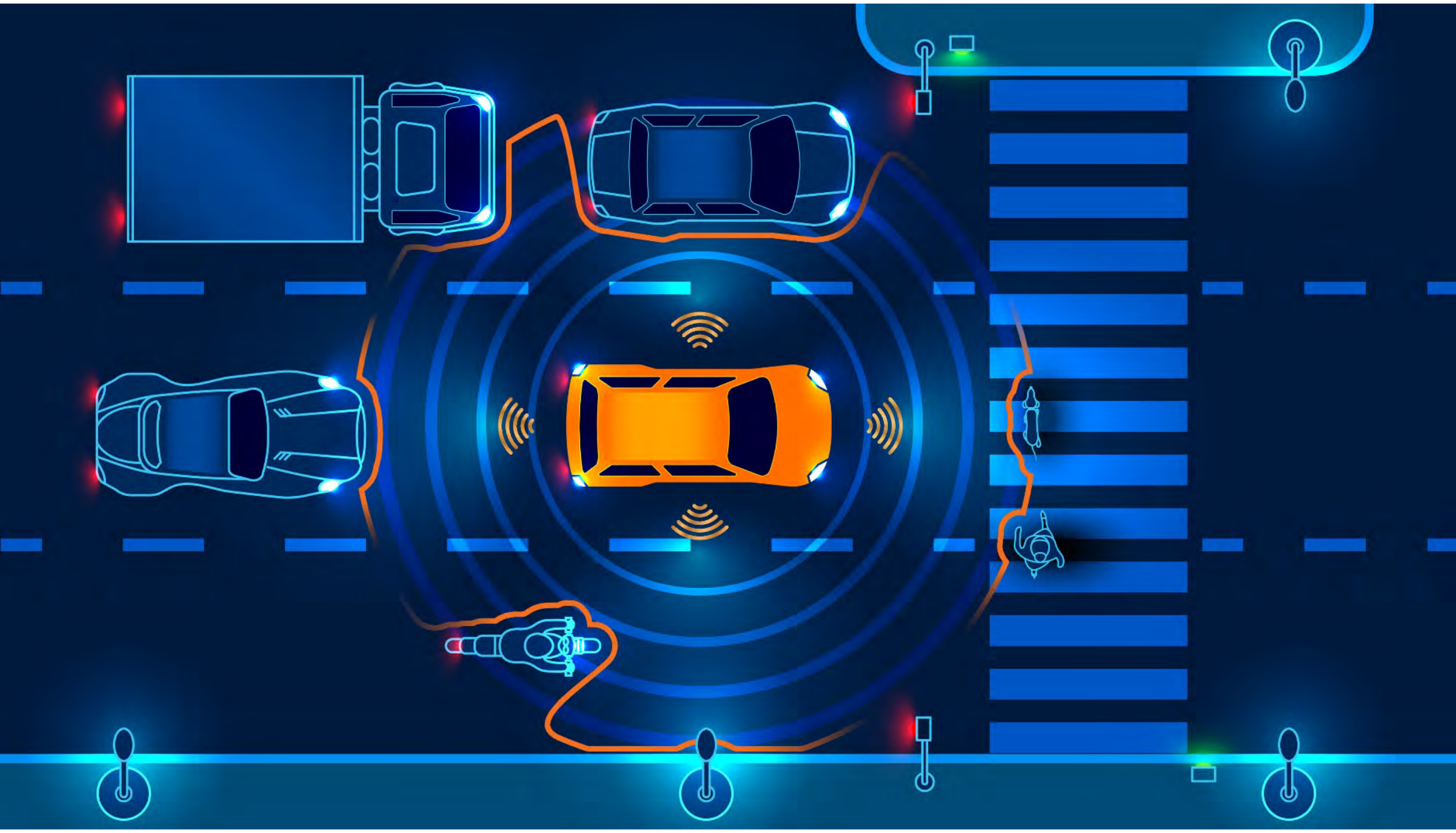
- The federal government, through USDOT, is responsible for regulating motor vehicles and equipment, enforcing those standards, and providing federal policy guidance. NHTSA is responsible for enhancing the safety of vehicles, including developing and enforcing Federal Motor Vehicle Safety Standards. The Federal Highway Administration is responsible for improving mobility and ensuring the safety of U.S. highways.
- States are responsible for vehicle licensing and registration, traffic laws and enforcement, and motor vehicle insurance and liability regimes.

Additional literature relies on ADS 2.0, including Fraade-Blanar et al.'s *Measuring Automated Vehicle Safety: Forging a Framework*; Trimble, Loftus-Otway, and Gallun's *Implications of Automation for Motor Vehicle Codes*; and the U.S. Government Accountability Office's *Comprehensive Plan Could Help DOT Address Challenges*.

Some international examples of research on the roles and responsibilities for safety come from Canada and Australia. Canada has also done work on roles and responsibilities for safety. The Policy and Planning Support Committee (2019) published a policy framework for Canada.[40] This framework provides a set of policy principles for all jurisdictions in Canada to follow as they

[38] Shai Shalev-Shwartz, Shaked Shammah, and Amnon Shashua, "On a Formal Model of Safe and Scalable Self-Driving Cars," 2017, 1–37, http://arxiv.org/abs/1708.06374.
[39] National Highway Traffic Safety Administration and US Department of Transportation, "Automated Driving Systems: A Vision for Safety 2.0," 2016, https://doi.org/10.13227/j.hjkx.2016.02.023.
[40] Policy and Planning Support Committee Working Group, "Automated and Connected Vehicles Policy Framework for Canada" 2019.

safely test and deploy vehicles.[41] The Canadian federal government has created a safety assessment for automated driving in Canada with 13 outcomes that vehicles equipped with ADS features should be able to perform.[42] Canada has also released a safety framework for Automated and Connected Vehicles.[43] Australia's National Transport Commission released a document on a national regulatory strategy for the safe operation of AVs in June 2020.[44]



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[41] Policy and Planning Support Committee Working Group, "Automated and Connected Vehicles Policy Framework for Canada" 2019.
[42] Transport Canada, "Safety Assessment for Automated Driving Systems in Canada," no. January (2019): 26.
[43] Transport Canada, "Canada's Safety Framework for Automated and Connected Vehicles.," no. February (2019): 25.
[44] National Transport Commission, "In-Service Safety for Automated Vehicles Decision Regulation Impact Statement," 2020.

4.3.2 Development of Safety Metrics

AV safety metrics research encompasses considerations of measures, goals, baseline assumptions, and comparisons with human operated vehicles. Metrics are a defined calculation, while measures are concepts. Metrics and measures may be of outputs or of outcomes and include indicators as well. The appropriate metric depends on the applicable goal. A key issue for the development of safety metrics questions is the relevant safety baseline.

The appropriate metric depends on the applicable goal

Common metrics referenced in literature and practice include:

- **Intervention** (when the safety driver takes control from the ADS in a potential crash scenario)
- **Disengagement** (deactivation of the ADS when a failure is detected). California requires OEMs who test on public roads to submit an annual report detailing disengagements.
- **Miles per intervention.** This tracks the often-used metric of miles per disengagement indicating how frequently a human has to make a critical safety decision. OEMs like Cruise and Aurora suggest a different metric would give a better picture of safety but offer no specific alternative.[45]
- **Intel's Responsibility Sensitive Safety Metric** quantifies an interpretation of the "Duty of Care" from tort law
- **Metrics that have been considered at the federal level** include:
  - NHTSA's Instantaneous Safety Metric, which measures safety related to the outcome of a situation and the probability of a crash occurring had actions varied, and
  - NHTSA's Testable Use Cases project identified frameworks for establishing sample preliminary ADS safety tests.

The Virginia Tech Transportation Institute (2019) is developing develop tools, metrics, and data resources to support ADS safety.[46] Most of its safety scenario protocols as well as its safety framework identify a range of metrics.

Other metrics focus on more individual aspects of safety. Two potential metrics are fatalities and injuries. Kalra and Paddock (2016) present a case that traffic fatalities and injuries are rare events compared to vehicle miles travelled and are therefore not a valid measure of safety for testing purposes.[47] As mentioned above, Griffor, Greer, and Wollman (2019) take the position that subjective metrics are difficult to use, and objective measurements should be considered instead. They suggest one alternative metric of safety to consider is the disengagement of the ADS;where a crash might have occurred without the human intervention.[48]

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[45] Griffor, Greer, and Wollman, "Workshop Report : Consensus Safety Measurement Methodologies for Automated Driving System-Equipped Vehicles NIST Special Publication 1900-320 Workshop Report : Consensus Safety Measurement Methodologies for Automated Driving System-Equipped Vehicles," 2019.

[46] Griffor, Greer, and Wollman., "Workshop Report : Consensus Safety Measurement Methodologies for Automated Driving System-Equipped Vehicles NIST Special Publication 1900-320 Workshop Report : Consensus Safety Measurement Methodologies for Automated Driving System-Equipped Vehicles," 2019.

[47] Kalra and Paddock, "Driving to Safety: How Many Miles of Driving Would It Take to Demonstrate Autonomous Vehicle Reliability?"

[48] NIST Special Publication, "Workshop Report : Consensus Safety Measurement Methodologies for Automated Driving System-Equipped Vehicles NIST Special Publication 1900-320 Workshop Report : Consensus Safety Measurement Methodologies for Automated Driving System-Equipped Vehicles."

4.4 Rethink "driver" (user) education and consumer interaction with the technology, including on automated vehicles, micromobility, and identify models to ensure user understanding of capabilities of technology

Literature around education of AV users often focuses on low level automation. As AVs become more widespread and reach these higher automation levels, some research argues that education of the AV users will be less important.[49] With full deployment projected in 2050 or beyond, it appears interim education efforts will be needed. Less research is focused on mobility engagement and models for user understanding, but some studies address user understanding of low-level automation.[50] A research gap appears to exist on user education and mobility engagement, as well as on the best model for mobility engagement and understanding.

4.4.1 Rethink Driver (User) Education and Mobility Engagement

There is limited publicly available research on education needs for the users' vehicles with ADS. More research is available on user education for advanced driver assistance systems. User education and understanding of advanced driver education systems is described in Section 4.4.2. The American Association of Motor Vehicle Administrators (AAMVA, 2018) addresses how AV technology will directly impact various aspects of licensing, including user training, testing, and licensing programs.[51] As AVs are deployed, users will need to receive proper training on the operation and limitations of AVs. AAMVA suggests that the training should educate consumers on the limitations and capabilities of AVs, risks of misuse, and how to deal with emergency situations related to the AV. The training should also encompass all safety features to ensure consumers will use the products within the established parameters.[52] Under the current federal framework, the states are to be responsible for developing general training.

As AVs are deployed, users will need to receive proper training on the operation and limitations of AVs

Manser et al. (2019) address training that drivers need to operate ADS and notes the absence of methods to train drivers on its use.[53] The project goal was to develop training protocol guidelines that could be used by stakeholders to train operators of vehicles with partial driving automation to optimize driving safety and comfort. Manser et al.'s results suggest that having a variety of training protocols are most beneficial in terms of driver cognitive load and visual scanning as opposed to short-term changes in performance.[54] Requirements for user education

[49] American Association of Motor Vehicle Administrators, "Jurisdictional Guidelines for the Safe Testing and Deployment of Highly Automated Vehicles," no. May (2018): 60.
[50] D.V McDonald, A., Carney, C., & McGehee and AAA Foundation for Traffic Safety, "Vehicle Owners' Experiences with and Reactions to Advanced Driver Assistance Systems," no. September (2018).
[51] American Association of Motor Vehicle Administrators, "Jurisdictional Guidelines for the Safe Testing and Deployment of Highly Automated Vehicles."
[52] American Association of Motor Vehicle Administrators.
[53] Michael P. Manser et al., "Driver Training Research and Guidelines for Automated Vehicle Technology," 2019.
[54] Manser et al.

will change as the number and type of AVs are on the road.**[55]** Referenced here is further research on driver licensing for AVs as well.[56]

4.4.2 Consumer Interaction and User Understanding of the Technology

The research around user understanding and mobility shows that while owners of low-level (SAE levels 1 and 2) AVs like the vehicles and technology, it is not fully understood. Further, users are unlikely to proactively seek further information about the technology. AAMVA notes that some consumer education will come from states.[57] It suggests that states should promote consumer education on the use of AV functions and encourage communication and engagement between dealers and consumers around sections in the vehicle owner's manual that relate to automated driving functions. AAMVA also contends that states should encourage manufacturers, dealers, and insurance companies to provide incentives for consumers to receive training on the use of ADS functions.[58]

A significant portion of research around user understanding of the technology comes from the AAA Foundation for Traffic Safety. McDonald, Carney, and McGehee (2018) examine knowledge, understanding, opinions of and experiences with ADS technologies among drivers who own and regularly drive vehicles equipped with ADS systems.[59] The results indicate that the majority of drivers generally have favorable impressions of ADS technologies, would buy them again, and would recommend the technologies to others. However, their results indicated a lack of understanding on the limitations of the technologies; showing a widespread willingness of drivers to take their attention from the roadway. Few respondents to the survey reported seeking information to understand the ADS technologies in their vehicles from any sources beyond the dealership, owner's manual, and their own experience via trial and error; only about 1 in 10 reported seeking information on the internet.[60] The authors contend that understanding how drivers seek information regarding their ADS technologies is critical for the industry to better meet educational needs.[61] User understanding of technology is especially important for senior citizens. The Massachusetts Institute of Technology Age Lab found that a majority of respondents were willing to consider new forms of transportation, but few had taken advantage of alternatives.[62] Further, senior citizens were not considering alternatives and expressed less interest in fully autonomous vehicles.[63]

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[55] Tammy E. Trimble, Lisa Loftus-Otway, and Susanna Gallun, *Implications of Connected and Automated Driving Systems, Vol. 1: Legal Landscape*, *Implications of Connected and Automated Driving Systems, Vol. 1: Legal Landscape*, 2018, https://doi.org/10.17226/25296.
[56] Other research on driver licensing for AVs are Trimble, Loftus-Otway, and Gallun's *Implications of Connected and Automated Driving Systems Vol. 1: Legal Landscape* and the Governors Highway Safety Association's "Autonomous Vehicles Meet Human Drivers: Traffic Safety Issues for States and Preparing for Automated Vehicles: Traffic Safety Issues for States".
[57] American Association of Motor Vehicle Administrators, "Jurisdictional Guidelines for the Safe Testing and Deployment of Highly Automated Vehicles."
[58] American Association of Motor Vehicle Administrators.
[59] McDonald, A., Carney, C., & McGehee and AAA Foundation for Traffic Safety, "Vehicle Owners' Experiences with and Reactions to Advanced Driver Assistance Systems."
[60] McDonald, A., Carney, C., & McGehee and AAA Foundation for Traffic Safety.
[61] McDonald, A., Carney, C., & McGehee and AAA Foundation for Traffic Safety.
[62] Hillary Abraham et al. "Autonomous Vehicles and Alternatives to Driving: Trust, Preferences, and Effects of Age" 2016.
[63] Hillary Abraham et al. "Autonomous Vehicles and Alternatives to Driving: Trust, Preferences, and Effects of Age" 2016.

Hassol et al. (2019) focus on understanding public responses to AVs through surveys.[64] The paper shows that the process for gathering consumer preference information on AVs can be challenging. Hassol et al. note that survey results should be cautiously assessed, and AVs may be too new to provide reliable survey results.[65] The surveys reviewed in this paper suggest that there is mixed but negative-leaning interest in AVs.

Research suggests that models for engagement and understanding include public engagement campaigns and can be adapted from other technologies, including the adoption of EVs. The Governors Highway Safety Association (2016) notes that states should be in charge of public education campaigns and that these campaigns should be coordinated across states.[66] It suggests that the effectiveness of public education campaigns will be determined by the credibility of the messenger and perception by the receiver about the necessity and validity of the message; therefore, information and education campaigns from the public sector may be seen as more believable. The National Association of Governors (2018) identify that actions to increase the adoption of EVs such as marketing, outreach, and social media campaigns could be applied to increase the awareness of the benefits of new technologies like AVs.[67]

4.5 Consider coordination with traffic and law enforcement, including consideration of existing powers of states and local governments, particularly over vehicle registration and licensing, and right-of-way management, and how this impacts potential regulation of AVs, especially with regard to curb management.

As the testing and deployment of AVs on public roads expand, the research around coordination with traffic and law enforcement and the powers of states has expanded. However, the role of safety "at the curb" has received less attention. Much of the research in this category focuses on the role of states in the registration and licensing of AVs. More recently, research on traffic and law enforcement has been completed and some further research is in process. A future research opportunity exists around safety of the curbside and right of way.

As the testing and deployment of AVs on public roads expand, the research around coordination with traffic and law enforcement and the powers of states has expanded

4.5.1 Existing Powers of States Including Registration and Licensing Impact on Regulation of Automated Vehicles

[64] Joshua Hassol, David Perlman, Lora Chajka-Cadin, and Jingsi Shaw. "Understanding Surveys of Public Sentiment Regarding Automated Vehicles" 2019.
[65] Hassol et al, "Understanding Surveys of Public Sentiment Regarding Automated Vehicles."
[66] Governors Highway Safety Association, "Vehicles Meet Human Drivers: Traffic Safety Issues for States," 2016, 1–26.
[67] National Association of Governors, "Governors Staying Ahead of the Transportation Innovation Curve: A Policy Roadmap for States," 2018, 64p, https://www.nga.org/wp-content/uploads/2018/07/Transportation-Innovation-Roadmap-Final-Hi-Res-for-Posting-Online.pdf%0Ahttps://trid.trb.org/view/1532064.

Hedlund (2018) writes that the states should build on the role they already play in vehicle regulation. This includes incorporating ADS information into state data, such as vehicle registration, traffic violations, and crash reports; establishing law enforcement policies/procedures and training on ADS operations; and determining if vehicle insurance requirements should be adjusted for ADSs.[68]

AAMVA (2018) gives recommendations for states on vehicle registration and licensing of AVs. As testing and deployment of AVs expand, it will be necessary to distinguish AVs from non-automated vehicles in mixed-fleet operations.[69] AAMVA finds that several jurisdictions already require the use of special registrations for AVs tested on public roadways. When jurisdictions are considering how to manage registrations, AAMVA recommended that they review their titling process. In the licensing process, jurisdictions will need to review laws to ensure current laws allow the operation of Level 4 and 5 AVs. New driver education training will be needed as well as new training for motor vehicle examiners and driver education trainers.[70]

Best practices for states include providing licensing and registration procedures and reviewing traffic laws and regulations that may serve as barriers to operation of ADS. To support these efforts, NHTSA recommends defining "motor vehicle" under ADS laws to include any motor vehicle operating on the roads and highways of the applicable state; licensing ADS entities and test operators for ADSs; and registering all vehicles equipped with ADSs and establishing proof of financial responsibility requirements in the form of surety bonds or self-insurance. These efforts provide states with the same information currently collected for conventional motor vehicles and improve the state recordkeeping for ADS operation.[71]

4.5.2 Law Enforcement and Automated Vehicles

Zmud et al. (2017) note that enforcing traffic laws will likely become more complex when there is a mix of road users driving non-automated vehicles with vehicles of various degrees of automation.[72] Impaired or distracted driving laws may not apply to vehicles that do not require active engagement of a driver but will still apply to those with less automation.[73] The level of traffic law enforcement will decline as the vehicle fleets increase in automation levels.

Zmud et al (2018) also suggest that some aspects of driver licensing, along with associated agency functions such as driver testing, may be phased out if a point is reached where most vehicles are automated. The Governor's Highway Safety Association describes a significant list of needs by law enforcement:[74]

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[68] James Hedlund and Governors Highway Safety Association, "Preparing for Automated Vehicles: Traffic Safety Issues for States," 2018, 41p, https://www.ghsa.org/sites/default/files/2018-08/Final_AVs2018.pdf%0Ahttps://trid.trb.org/view/1532106.

[69] American Association of Motor Vehicle Administrators, "Jurisdictional Guidelines for the Safe Testing and Deployment of Highly Automated Vehicles."

[70] American Association of Motor Vehicle Administrators.

[71] National Highway Traffic Safety Administration and US Department of Transportation, "Automated Driving Systems: A Vision for Safety 2.0."

[72] Johanna Zmud et al., *Advancing Automated and Connected Vehicles: Policy and Planning Strategies for State and Local Transportation Agencies*, 2017, https://doi.org/10.17226/24872.

[73] Zmud et al.

[74] Governors Highway Safety Association, "Automated Vehicle Safety Expert Panel: Engaging Drivers and Law Enforcement," 2019, 26p, https://www.ghsa.org/sites/default/files/2019-08/AV Safety White Paper_FINAL.pdf%0Ahttps://trid.trb.org/view/1645915.

- A uniform method to identify an AV on the road; assurance that all AVs will recognize and respond appropriately to direction from law enforcement and traffic situations
- Agreement from states, AV developers, and NHTSA on how to reconcile conventional driving practices with AV's compliance with traffic laws
- Uniform procedures and training for law enforcement and first responders for dealing with an AV at a crash site
- Uniform methods for law enforcement to access data from an AV after a crash
- Agreement on responsibility for AV operations and crashes for a level 4 and 5 AVs
- Mechanisms for law enforcement to acquire and analyze vehicle data relevant to determining crash responsibility[75]

Terry et al. (2018) determined the types of interactions that public safety authorities, such as police, fire fighters, and emergency medical personnel, currently have with AVs and then breaks down those interactions through a detailed task analysis.[76] The participant feedback indicates several potential opportunities for improved interactions between public officials and future ADS-equipped vehicles. Public safety officials benefit from predictable and consistent actions by vehicles in all the scenarios both in terms of safety and efficiency.[77]

There are several research efforts around first responders and AVs. These include Virginia Tech Transportation Institute's active project "Response of Autonomous Vehicles to Emergency Response Vehicles," and U.S. federal government activities identified in NHTSA's *Ensuring American Leadership in Automated Vehicle Technologies - Automated Vehicles 4.0*.Two ADS developers, Waymo[78] and Uber[79], have also publicly released emergency response and law enforcement guides. There have been some work around remote operators for AVs, especially for freight deliveries.[80] Hampshire et al. (2020) argue that remote operators for AVs could increase safety, speed the deployment of AVs, and provide employment.[81]

4.5.3 Insurance and Liability

There is limited research around insurance needs for AVs since they are not in routine deployment. Clements and Kockelman (2017) note that safety improvements from AVs will require insurance agencies to adapt and to possibly create new business models.[82] In the current model, insurance companies sell policies to individual vehicle owners and human drivers are liable for crashes. Smith (2016) notes that as AV use grows, product liability models are like

[75] Governors Highway Safety Association.
[76] T. Terry et al., "An Examination of Emergency Response Scenarios for ADS," no. October (2018).
[77] Terry et al.
[78] Waymo, "Waymo Fully Self-Driving Chrysler Pacifica Emergency Response Guide and Law Enforcement Interaction Protocol," 2018.
[79] Uber Advanced Technology Group, "Uber Advanced Technologies Group Public Safety Officials and First Responders' Guide," 2019.
[80] For more on remote operators, see Robert C. Hampshire et al., "Beyond Safety Drivers: Applying Air Traffic Control Principles to Support the Deployment of Driverless Vehicles," Dale Lewis's "Operating Economics of Long Haul Trucks," and the American Center for Mobility's "Preparing the Workforce for Automated Vehicles"
[81] Robert C. Hampshire et al., "Beyond Safety Drivers: Applying Air Traffic Control Principles to Support the Deployment of Driverless Vehicles," *PLOS ONE* 15, no. 5 (2020): 1–9, https://doi.org/10.1371/journal.pone.0232837.
[82] Lewis M Clements and Kara M. Kockelman, "Economic Effects of Automated Vehicles," 2017., 1–19.

to replace current models of no fault, comparative negligence, and the like.[83] Albright et al. (2015) estimate that AVs could shrink the automobile insurance industry by nearly 60%.[84]

4.6 Address new potential concerns related to public health and, including impacts from COVID-19

Public health research focuses on reduction of morbidity and mortality related to human factors and driving. Some research has suggested public health impacts include air quality and physical activity. As the COVID-19 pandemic hit in early 2020, there has been research on shared mobility as a vector, containment strategies, and several demonstrations of AVs for contactless transportation of medical materials.

Rojas-Rueda et al (2020) discuss AVs' potential to reduce morbidity and mortality from motor vehicle crashes and how they may help reshape cities to promote healthy urban environments.[85] However, they also state that while AVs have the potential to shape urban life and significantly modify travel behaviors, absent proper policies and incentives, they could increase some health risks such as air pollution, noise, and sedentarism. The Altarum Institute (2016) also notes that AVs may discourage healthy behaviors like biking and walking.[86] All discussion in this area is, of course, speculative until increased deployments are in place.

The literature suggests that a healthy model of AV use includes fully EVs in a system of ridesharing. Rojas-Rueda et al. emphasize that public health will benefit if proper policies and regulatory frameworks are implemented before the complete introduction of AVs into the market.[87]

Given the recent occurrence of the COVID-19 pandemic, little formal research has been undertaken on the potential impacts on AVs. There have been limited examples of using of AVs for contactless freight delivery; but these applications have not been evaluated formally.

[83] Bryant Walker Smith, "Automated Driving and Product Liability," *Detroit College of Law at Michigan State University Law Review*, 2016.
[84] Jerry Albright et al., "Marketplace of Change: Automobile Insurance in the Era of Autonomous Vehicles," no. October (2015): 52, https://assets.kpmg.com/content/dam/kpmg/pdf/2016/06/id-market-place-of-change-automobile-insurance-in-the-era-of-autonomous-vehicles.pdf.
[85] David Rojas-Rueda et al., "Autonomous Vehicles and Public Health," *Annual Review of Public Health* 41, no. 1 (2020): 329–45, https://doi.org/10.1146/annurev-publhealth-040119-094035.
[86] Jud Richland, Jim Lee, Erin Duggan Butto. "Steering Autonomous Vehicle Policy: The Role of Public Health" 2016.
[87] Rojas-Rueda et al., "Autonomous Vehicles and Public Health."

5 Further Research Opportunities

The suggestions below identify topics for future research to inform and focus the important discussion around *Safety Scenarios and Engagement During Transition to Highly Automated Vehicles*. These topics will be evaluated by the Forum in coordination with the appropriate TRB Committees and staff to determine which topics can be expanded into more detailed research statements and proposals. Where possible, crossover to other Topical Papers has been identified to assist with the development of more robust and cross-issue research statements.

Subtopic	Research Opportunity	Crossover to Other Topics
4.1	Identify effective training, management, standards, and oversight for establishing strong safety cultures in AV producers and operators.	*None*
4.1	Assess risk of efficiency attacks versus those focusing on weaponizing vehicles; develop best practices to mitigate risks and consequences of attacks.	*None*
4.1	Identify best practices for privacy protection.	*Data Sharing and Governance*
4.1	Assess voluntary or industry standard setting safely models and create options for applying to AVs	*None*
4.1	Develop and assess alternative audit, validation, and certification approaches, including aviation schemes, testing center approaches such as American Mobility Center, GoMentum Station, AVerify, and Aviation Federally Funded Research and Development Centers.	*None*
4.2	Create safety scenario repositories, assess coverage, and examine presence and evaluation of edge cases.	*None*
4.2	Assess performance-based safety standards and testing based on safety scenarios.	*None*
4.3	Research the roles and responsibilities that cities may have for ensuring safety of AVs.	*None*
4.3	Develop potential alternatives to disengagements as a safety indicator metric.	*None*

Subtopic	Research Opportunity	Crossover to Other Topics
4.4	Validate education for specific demographic subsets including aging population.	*Social Impacts, Equity & Accessibility*
4.5	Create a uniform guidebook for law enforcement and first responders.	*None*
4.5	Create a guidebook covering insurance and liability considerations for AV incidents.	*None*
4.6	Identify best practices in areas such as sanitation, contact tracing, and social distancing seen in other modes (rail, transit, and air) that would specifically apply to AVs.	*Social Impacts*
4.3	Evaluate metrics that could lead to AV-specific standards, e.g. 20% or higher level of performance as compared to a human driver.	*None*

6 Appendix

A. Definition of Terms

ADA	Americans with Disabilities Act
ADS	Automated Driving System
AV	Automated Vehicle
EV	Electric Vehicle
FTA	Federal Transit Administration
HAV	Highly Automated Vehicle
LSAV	Low-Speed Automated Vehicle
MaaS	Mobility as a Service
NHTSA	National Highway Traffic Safety Administration
ODD	Operational Design Domain
OEDR	Object and Event Detection and Response
SAE	Society of Automotive Engineers
TNC	Transportation Network Company
USDOT	US Department of Transportation
VMT	Vehicle Miles Traveled

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